

**Liquid Pumps with Hermetically Sealed Motor Rotors****Cross Reference to Related Applications**

The present application is a regular application which claims priority from U.S. Provisional Patent Application 60/425,820, filed November 13, 2002, U.S. Provisional Patent Application 60/490, 615, filed July 28, 2003, and the U.S. Provisional Patent Application titled "Locally Powered Water Distillation System" with inventors Dean Kamen and Kingston Owens, filed November 10, 2003 (serial no. not yet assigned), each of which is hereby incorporated herein by reference.

**Technical Field**

The present invention relates to liquid purification, and more particularly to liquid purification by vapor compression distillation comprising a liquid ring pump with hermetically sealed motor rotors.

**Background of the Invention**

A dependable source of clean water eludes vast segments of humanity. For example, the Canadian International Development Agency reports that about 1.2 billion people lack access to safe drinking water. Published reports attribute millions and millions of deaths per year, mostly children, to water related diseases. Many water purification techniques are well known, including carbon filters, chlorination, pasteurization, and reverse osmosis. Many of these techniques are significantly affected by variations in the water quality and do not address a wide variety of common contaminants, such as bacteria, viruses, organics, arsenic, lead, mercury, and pesticides that can be found in water supplies in the developing world and elsewhere. Some of these systems require access to a supply of consumables, such as filters or chemicals. Moreover, some of these techniques are only well suited to centralized, large-scale water systems that require both a significant infrastructure and highly trained operators.

The ability to produce reliable clean water without regard to the water source, on a smaller, decentralized scale, without the need for consumables and constant maintenance is very desirable, particularly in the developing world.

The use of vapor compression distillation to purify water is well known and can address many of these concerns. However, the poor financial resources, limited technical assets, and low population density that does not make it feasible to build centralized, large-scale water systems in much of the developing world, also limits the availability of adequate, affordable, and reliable power to operate vapor compression distillation systems, as well as hindering the ability to properly maintain such systems. In such circumstances, an improved vapor compression distillation system and associated components that increases efficiency and production capability, while decreasing the necessary power budget for system operation and the amount of system maintenance required may provide a solution.

### **Summary of the Invention**

In a first embodiment of the invention there is provided a liquid purification system is provided that advantageously may be compact, inexpensive, and easily maintained. One embodiment has a distillation device with a liquid ring pump and a fully rotatable housing with a single continuous shaft about which the liquid ring pump, motor and rotor rotates, and a second shaft supporting the rotatable housing, with an internal or external combustion engine, preferably having motor rotor and magnets hermetically sealed within the fluid pressure boundary of the distillation system.

Another alternative embodiment has a distillation device with a liquid ring pump encased in a fully rotatable housing within the head vapor space of a still. Systemic heat sources can be redirected through a multi-line heat exchanger to maximize energy efficiency during the vaporization step. Back-wash lines may be directed to the intake from the head chamber of the evaporator/condenser, to keep unique flip-filters in the intake from fouling and to add heat into the heat exchange network. Further, a method of eliminating mist may be incorporated in the liquid ring pump component to eliminate contaminated liquid droplets entrained in the vapor and prevent them from being carried along to the condenser and thereby contaminating the purified product.

Another particular embodiment has a distillation device with a liquid ring pump and a fully rotatable housing with a single continuous shaft about which the liquid ring pump, motor and rotor rotates, and a second shaft supporting the rotatably housing, with an internal or external combustion engine and siphon pump in a lower reservoir to siphon liquid into the chamber of the liquid ring pump. The result is a highly efficient, easily accessed and maintained, relatively simple and inexpensive system for purifying a liquid.

Yet another is a method for removing contaminants from water comprising driving an electric generator by means of a thermal cycle engine for generating electrical power capacity, the thermal cycle engine including a burner for combusting a fuel, employing at least a portion of the electrical power capacity of the electric generator for powering a water purification unit, supplying source water to an input of the water purification unit, conveying heat output of the thermal cycle engine for supplying heat to the water purification unit to reduce the amount of electrical power required to purify the water. Further embodiments may additionally comprise one or all of transferring heat from an exhaust gas of the burner to source water, heating an enclosure surrounding the water purification unit to reduce thermal loss, vaporizing untreated water, and condensing vaporized water into distilled water product.

Another embodiment employs a backpressure regulator comprising a hinged arm having a closed position and a movable stop shaped to cover a port connected to a pressurized conduit, the stop being held by a retainer attached to the arm, and the stop being positioned adjacent to the port when the arm is in the closed position, wherein the arm is away from the closed position when the pressure conduit exceeds a set point, and the arm is in the closed position when the pressure in the conduit is less than the set point.

Additional advantages and specific aspects of the system will be more readily ascertained from the drawings and the accompanying detailed description of the preferred embodiments, below.

### **Brief Description of the Drawings**

The foregoing features of the invention will be more readily understood by reference to the following detailed description, taken with reference to the accompanying drawings, in which:

5 **Figure 1A** is a conceptual flow diagram of a possible embodiment of the overall system designed in accordance with the present invention.

**Figure 1B** is a schematic block diagram of a power source for use with the system shown in Figure 1A in accordance with an embodiment of the invention.

**Figure 2** shows the component power unit and water purification unit in accordance with a  
10 preferred embodiment of the present invention.

**Figure 3** is a schematic block diagram of an auxiliary power unit for providing electrical power and heat for water purification in accordance with the present invention.

**Figure 4** is a schematic overview of an integral power unit/water purification system in accordance with an embodiment of the present invention.

15 **Figure 5A** is a cross-sectional and top view of a rotor and stator in accordance with a particular embodiment showing the support structure for the input, the vanes and chambers between the vanes, and the rotating drive shaft.

**Figure 5B** is a side top view of a rotor and stator corresponding to the embodiment shown in Figure 5A, showing the support structures for the input and output, the vanes, the eccentric  
20 configuration within the housing unit, and the drive shaft.

**Figure 5C** is a top view of a rotor and stator corresponding to the embodiment shown in Figures 5A and 5B, showing support structures for input and output, the vanes, the eccentric configuration within the housing unit, and the drive shaft.

**Figure 5D** is a cross-sectional view of a rotor and stator corresponding to the embodiment shown in Figures **5A** , **5B**, and **5C** showing vanes, drive shaft, and bearings.

**Figure 6A** is a schematic diagram of a liquid ring pump in accordance with a specific embodiment of the present invention.

5 **Figure 6B** is a top view of a rotor in accordance with an embodiment of the present invention showing multiple vanes and chambers between the vanes, and intake and exit holes in each individual chamber.

**Figure 7A** is further detail of a liquid ring pump in accordance with a specific embodiment of the present invention showing the stationary intake port and the rotating drive shaft, rotor  
10 and housing unit.

**Figure 7B** is a view of a seal which may be present between the stationary and rotor sections of a liquid ring pump in accordance with a specific embodiment of the present invention, separating the intake orifice from the exit orifice.

**Figure 8** is a cross-sectional view of a liquid ring pump according to an embodiment of the  
15 present invention, showing a capacitive sensor.

**Figure 9** is a cross-sectional view of a liquid ring pump according to an embodiment of the present invention showing the eccentric rotor, rotor vanes, drive shaft with bearings, the rotating housing unit for the liquid ring pump, the still housing, and the cyclone effect and resulting mist and water droplet elimination from the steam.

20 **Figure 10** is a cross-sectional view of a particular embodiment of a liquid ring pump in accordance with the present invention, showing a hermetically sealed motor rotor and magnets that are housed within the pressure and fluid boundary of the system, the drive shaft, rotor, and rotating housing wherein water droplets are spun off and recycled back to the base

water level of the pump, and a siphon pump for drawing water up into the main chamber of the pump from the lower reservoir.

**Figure 11** is a detailed view of the hermetically sealed motor rotor shown in **Figure 10**.

**Figure 12A** is a view of the external pump housing and motor housing for an embodiment in

5 accordance with that of **Figure 10**, showing steam input and output ports.

**Figure 12B** is a cross-sectional view of **Figure 12A**, showing the motor within its housing, the motor shaft and rotor, and the lower reservoir.

**Figure 12C** is another cross-sectional view of **Figure 12A** through a different plane, again showing the motor within its housing, the motor shaft and rotor, and the fluid line connecting

10 to the lower reservoir, wherein the siphon pump is now visible.

**Figure 13** is a detailed cross-sectional view of the lower reservoir of **Figure 12C** showing more clearly the siphon pump, the surrounding bearings, and fluid line.

**Figure 14A** is a schematic of an overall system in accordance with an embodiment of the invention, showing the intake passing through a pump, into a heat exchanger, continuing into  
15 the core of the still wherein a heater vaporizes the liquid into steam in the head section after which the steam flows to the compressor and into the condenser, after which condensed product can be recovered.

**Figure 14B** is a detailed schematic of an evaporator head and blowdown level sensor housing, showing an external connecting valve between source and blowdown fluid lines.

20 **Figure 15** shows an alternative embodiment of an evaporator/condenser having elastomer tube and shell seals.

**Figure 16A** is a cross-sectional view of the evaporator/condenser core section of the still.

Individual heating layers and ribs in accordance with a particular embodiment are shown,

with input and output manifolds and bolts, for connecting and attaching to the fluid distribution manifold.

**Figure 16B** is a detail of a cross-section of an evaporator/condenser core section in accordance with **Figure 16A**, showing how the ribs effectively partition the steam/evaporation from the liquid/condensation layers.

**Figure 17A** is a view of one face of the pump side of a fluid distribution manifold.

**Figure 17B** is a view of a second face of the pump side of a fluid distribution manifold.

**Figure 17C** is a view of one face of the evaporator/condenser side of a fluid distribution manifold.

**Figure 17D** is a view of a second face of the evaporator/condenser side of a fluid distribution manifold.

**Figure 18A** is a side view of a coupler in accordance with an embodiment of the present invention, for connecting various flow lines and components in the overall system.

**Figure 18B** is a top view of a coupler as depicted in **Figure 12A**.

**Figure 19A** is a schematic diagram of a multi-line heat exchanger in accordance with a specific embodiment of the present invention showing multiple two-channel heat exchangers that are plumbed to produce a multi-line effect.

**Figure 19B** is an alternative heat exchanger in accordance with a particular embodiment of the present invention showing a single three-channel heat exchanger wherein heat from a product stream and blowdown stream exchange with a cold intake but not with each other.

**Figure 20** is a schematic overview of the system showing pressure measurement of the system using a cold sensor.

**Figure 21A** shows a view of a flip-filter with the intake stream and blowdown stream flowing through filter units, each filter unit rotating around a pivot joint about a center axis.

**Figure 21B** shows flip filter housings and an alternative embodiment of a multi-unit flip filter.

**Figure 22** shows a view of a manual switch for changing water flow through individual units of a flip-filter, enabling backwashing of the units without having to physically flip the filters.

5 **Figure 23A** is side view of a backpressure regulator in accord with an embodiment of the invention.

**Figure 23B** is a diagonal view of the backpressure regulator shown in **Figure 23A**.

**Figure 24A** is a side view of a backpressure regulator with a vertically positioned port in accord with an embodiment of the invention.

10 **Figure 24B** is a diagonal view of the backpressure regulator shown in **Figure 24A**.

**Figure 25** is a schematic of a backpressure regulator implemented into a process, consistent with an embodiment of the invention.

**Figure 26A** is a diagonal view of a backpressure regulator in accord with an embodiment of the invention.

15 **Figure 26B** shows a close-up view of section **C** of **Figure 26A**, depicting a notch in the port of the backpressure regulator.

**Figure 27A** is a cutaway side view of a backpressure regulator consistent with an embodiment of the invention.

### **Detailed Description of Specific Embodiments**

20 Definitions. As used in this description and the accompanying claims, the following terms shall have the meanings indicated, unless the context otherwise requires.

The term “purifying” as used herein, and in any appended claims, refers to substantially reducing the concentration of one or more contaminants to less than or equal to

specified levels or otherwise substantially altering the concentration of one or more contaminants to within a specified range.

The term “specified levels” as used herein refers to some desired level of concentration, as established by a user for a particular application. One instance of a specified level may be limiting a contaminant level in a fluid to carry out an industrial or commercial process. An example is eliminating contaminant levels in solvents or reactants to a level acceptable to enable an industrially significant yield in a chemical reaction (e.g., polymerization). Another instance of a specified level may be a certain contaminant level in a fluid as set forth by a governmental or intergovernmental agency for safety or health reasons. Examples might include the concentration of one or more contaminants in water to be used for drinking or particular health or medical applications, the concentration levels being set forth by organizations such as the World Health Organization or the U.S. Environmental Protection Agency.

A conceptual flow diagram of an overall system in accordance with one possible embodiment of the present invention is shown in Figure 1A, with liquid flow paths indicated by arrows. In an embodiment of this type, liquid flows through the system from an intake 00 into an exchanger 400 wherein exchanger 400 receives heat from at least one of a plurality of sources including a condenser 200, a head 300, and exhaust (not shown) from a power source such as an internal or external combustion engine. Liquid continues flowing past heat exchanger 400 into a sump 500 and into a core 600 in thermal contact with condenser 200. In the core 600, the liquid is partially vaporized. From core 600, the vapor path proceeds into head 300 in communication with a compressor 100, and from there into condenser 200. After vapor is condensed, liquid proceeds from condenser 200 through heat exchanger 400, and finally into an exhaust region 700 and then out as final distilled product.

A power source 800 is used to power the overall system. Power source 800 may be coupled to a motor 150 (not shown) that is used to drive compressor 100, particularly when compressor 100 is a steam pump, such as a liquid ring pump. The power source 800 may also be used to provide electrical energy to the other elements of the system shown in Figure 1A. Power source 800 may be, for example, an electrical outlet, a standard internal combustion (IC) generator or an external combustion generator. An IC generator and an external combustion generator advantageously produce both power and thermal energy as

shown in Figure 1B, where engine 802 produces both mechanical and thermal energy. Engine 802 may be either an internal combustion engine or an external combustion engine. A generator 804, such as a permanent magnet brushless motor, is coupled to a crankshaft of the engine 802 and converts the mechanical energy produced by the engine 802 to electrical energy, such as power 806. Engine 802 also produces exhaust gases 808 and heat 810. The thermal energy produced by the engine 802 in the form of exhaust gas 808 and heat 810 may advantageously be used to provide heat to the system.

Alternatively, heat from electrical power generator 800 may be recaptured by channeling the engine exhaust into the insulated cavity that surrounds the still, which lies between external housing and the individual still components. In such an embodiment, exhaust blows across a finned heat exchanger that heats source liquid as it enters evaporator 600.

Returning to Figure 1A, the power source 800 is preferably an external combustion generator such as a Stirling engine generator. A Stirling engine produces a thermal energy output in the form of exhaust gases and radiative heat. The exhaust gases of a Stirling engine are relatively hot, typically 100°C to 300°C, and represent 10 to 20% of the thermal energy produced by the Stirling engine. The exhaust produced by the Stirling engine is typically a clean exhaust, comprising mainly CO<sub>2</sub>, N<sub>2</sub>, and water. A cooler of the Stirling engine may be used to reject heat produced by the engine to the environment around the engine. Use of an external combustion engine, such as a Stirling cycle engine, to provide mechanical power for conversion into electrical power by means of a generator is described in detail in US Patent No. 6,536,207 (Kamen et al.), issued March 25, 2003, and incorporated herein by reference. For additional information relating to preferred embodiments of a Stirling cycle engine, see co-pending U.S. Patent application serial number 09/517,245, filed March 2, 2000, entitled "Stirling Engine Thermal System Improvements", and co-pending U.S. Patent application serial number 09/517,808, filed March 2, 2000, entitled "Auxiliary Power Unit," which are herein incorporated by reference in their entirety.

Pre-treatment of the liquid to be distilled, preferably water, may be conducted, in which case pre-treatment may occur prior to or within intake 00. Pre-treatment operations may include any or all of gross-filtering; treatment with chemical additives such as polyphosphates, polyacetates, organic acids, or polyaspartates; and electrochemical treatment

such as an oscillating magnetic field or an electrical current; degassing; and UV treatment. Additives may be added in liquid form to the incoming liquid stream using a continuous pumping mechanism such as a roller pump or pulsatile pump, including a standard diaphragm pump or piezoelectric diaphragm pump. Alternatively, the additives may be added by a semi-continuous mechanism using, for example, a syringe pump, which would require a re-load cycle, or a batch pumping system, wherein a small volume of the additive would be pumped into a holding volume or reservoir external to the system that uniformly mixes the additive with the liquid before the liquid flows into the system. It is also envisioned that the user could simply drop a prescribed volume of the additive into, for example, a bucket containing the liquid to be purified. Liquid additive may be loaded as either a lifetime quantity (i.e., no consumables for the life of the machine), or as a disposable amount requiring re-loading after consumption.

Additives could also be added in solid form, wherein such additives could be embedded in a time-release matrix inserted into the flow-through channel of intake 00. In this particular embodiment, replacement additive would need to be inserted periodically by the user. In yet another embodiment, a powder form of an additive could be added in a batch system wherein the powder is added, for example in tablet form, to an external reservoir containing water to be purified wherein the additive is uniformly mixed, similar to the batch system for adding liquid additives described above.

Post-treatment of the distilled product, preferably water, may occur, in which case post-treatment may occur preferably within an external output region (not shown). Post-treatment operations may include taste additives such as sugar-based additives for sweetening, acids for tartness, and minerals. Other additives, including nutrients, vitamins, stabilized proteins such as creatinine, and fats, and sugars may also be added. Such additives may be added either in liquid or solid form, whether as a time-release tablet through which the output liquid flows, or a powder added to an external reservoir such as through a batch system. Alternatively, the additive may be added to the output liquid via an internal coating of a separate collection reservoir or container, for example, by leaching or dissolution on contact. In such embodiments, the ability to detect purified liquid with and without the additive is preferred. Detection systems in accordance with embodiments of the present invention include pH analysis, conductivity and hardness analysis, or other standard

electrical-based assays. Such detection systems allow for replacement of additives, as needed, by triggering a signal mechanism when the additive level/quantity is below a pre-set level, or is undetectable.

In another embodiment, liquid characteristics, such as for example water hardness, is monitored in the output and may be coupled with an indicator mechanism which signals that appropriate additives should be added.

In yet another embodiment, ozone is systemically generated using, for example, electric current or discharge methods, and added to the output product for improved taste. Alternatively, air pumped through a HEPA filter may be bubbled through the output liquid to improve palatability of the final purified product.

It is envisioned that other embodiments may include means for detecting nucleic acids, antigens and bio-organisms such as bacteria. Examples of such detection means include nanoscale chemistry and biochemistry micro-arrays known in the field and currently commercially available. Such arrays may also be used to monitor the presence and/or absence of nutrients and other additives in the purified product, as discussed above

In another embodiment, UV treatment may be used post-purification, for example in a storage barrel or other container, to aid in maintenance of the purified product.

In another particular embodiment, a Stirling engine generator which produces exhaust high in CO<sub>2</sub> content is used as the power source **800** to power the overall system. In such an embodiment, the exhaust from the Stirling engine is funneled back to intake **00** and used to acidify the water to be purified as one means of pre-treatment. The acidification of the incoming water supply would result from the forced dissolution of the CO<sub>2</sub> (under pressure) in the exhaust, and the acidification may reduce any scaling, such as lime build-up, that occurs in the system. Alternatively, the CO<sub>2</sub> exhaust may be channeled into the purified product as a means for post-treatment acidification.

The system provided in accordance with embodiments of the present invention has two basic functional components that may be combined within a single integral unit or may be capable of separate operation and coupled as described herein for the purpose of local water purification. Figure 2 depicts an embodiment of the invention in which a power unit **2010** is coupled electrically, via cable **2014**, to provide electrical power to a vapor

compression water distillation unit **2012**, with exhaust gas from the power unit coupled to convey heat to the water distillation unit via an exhaust duct **2016**.

Thermal cycle engines are limited, by second law of thermodynamics, to a fractional efficiency, i.e., a Carnot efficiency of  $(T_H - T_C)/T_H$ , where  $T_H$  and  $T_C$  are the temperatures of the available heat source and ambient thermal background, respectively. During the compression phase of a heat engine cycle, heat must be exhausted from the system in a manner not entirely reversible, thus there will always be a surfeit of exhaust heat. More significantly, moreover, not all the heat provided during the expansion phase of the heat engine cycle is coupled into the working fluid. Here, too, exhaust heat is generated that may be used advantageously for other purposes. The total heat thermodynamically available (i.e., in gas hotter than the ambient environment) in the burner exhaust is typically on the order of 10% of the total input power. For a power unit delivering on the order of a kilowatt of electrical power, as much as 700 W of heat may be available in an exhaust stream of gas at temperatures in the vicinity of 200°C. In accordance with embodiments of the present invention, the exhaust heat, as well as the electrical power generated by an engine-powered generator, are used in the purification of water for human consumption, thereby advantageously providing an integrated system to which only raw water and a fuel need be provided.

Moreover, external combustion engines, such as Stirling cycle engines, are capable of providing high thermal efficiency and low emission of pollutants, when such methods are employed as efficient pumping of oxidant (typically, air, and, referred to herein and in any appended claims, without limitation, as "air") through the burner to provide combustion, and the recovery of hot exhaust leaving the heater head. In many applications, air is pre-heated, prior to combustion, nearly to the temperature of the heater head, so as to achieve the stated objectives of thermal efficiency. However, the high temperature of preheated air, desirable for achieving high thermal efficiency, complicates achieving low-emission goals by making it difficult to premix the fuel and air and by requiring large amounts of excess air in order to limit the flame temperature. Technology directed toward overcoming these difficulties in order to achieve efficient and low-emission operation of thermal engines is described, for example, in US Patent No. 6,062,023 (Kerwin, et al.) issued May 16, 2000, and incorporated herein by reference.

External combustion engines are, additionally, conducive to the use of a wide variety of fuels, including those most available under particular local circumstances, however the teachings of the present description are not limited to such engines, and internal combustion engines are also within the scope of the present invention. Internal combustion engines, however, impose difficulties due to the typically polluted nature of the exhausted gases, and external combustion engines are preferably employed.

An embodiment of a power unit **2010** is shown schematically in Figure 3. Power unit **2010** includes an external combustion engine **2101** coupled to a generator **2102**. In a preferred embodiment, the external combustion engine **2101** is a Stirling cycle engine. The outputs of the Stirling cycle engine **2101** during operation include both mechanical energy and residual heat energy. Heat produced in the combustion of a fuel in a burner **2104** is applied as an input to the Stirling cycle engine **2101**, and partially converted to mechanical energy. The unconverted heat or thermal energy accounts for 65 to 85% of the energy released in the burner **2104**. This heat is available to provide heating to the local environment around the power unit **2110** in two forms: a smaller flow of exhaust gas from the burner **2104** and a much larger flow of heat rejected at the cooler **2103** of the Stirling engine. Power unit **2110** may also be referred to as an auxiliary power unit (APU). The exhaust gases are relatively hot, typically 100 to 300°C, and represent 10 to 20% of the thermal energy produced by the Stirling engine **2101**. The cooler rejects 80 to 90% of the thermal energy at 10 to 20°C above the ambient temperature. The heat is rejected to either a flow of water or, more typically, to the air via a radiator **2107**. Stirling cycle engine **2101** is preferably of a size such that power unit **2010** is transportable.

As shown in Figure 3, Stirling engine **2101** is powered directly by a heat source such as burner **2104**. Burner **2104** combusts a fuel to produce hot exhaust gases which are used to drive the Stirling engine **2101**. A burner control unit **2109** is coupled to the burner **2104** and a fuel canister **2110**. Burner control unit **2109** delivers a fuel from the fuel canister **2110** to the burner **2104**. The burner controller **2109** also delivers a measured amount of air to the burner **2104** to advantageously ensure substantially complete combustion. The fuel combusted by burner **2104** is preferably a clean burning and commercially available fuel such as propane. A clean burning fuel is a fuel that does not contain large amounts of contaminants, the most important being sulfur. Natural gas, ethane, propane, butane,

ethanol, methanol and liquefied petroleum gas (“LPG”) are all clean burning fuels when the contaminants are limited to a few percent. One example of a commercially available propane fuel is HD-5, an industry grade defined by the Society of Automotive Engineers and available from Bernzomatic. In accordance with an embodiment of the invention, and as  
5 discussed in more detail below, the Stirling engine **2101** and burner **2104** provide substantially complete combustion in order to provide high thermal efficiency as well as low emissions. The characteristics of high efficiency and low emissions may advantageously allow use of power unit **2010** indoors.

Generator **2102** is coupled to a crankshaft (not shown) of Stirling engine **2101**. It  
10 should be understood to one of ordinary skill in the art that the term generator encompasses the class of electric machines such as generators wherein mechanical energy is converted to electrical energy or motors wherein electrical energy is converted to mechanical energy. The generator **2102** is preferably a permanent magnet brushless motor. A rechargeable battery **2113** provides starting power for the power unit **2010** as well as direct current (“DC”) power  
15 to a DC power output **2112**. In a further embodiment, APU **2010** also advantageously provides alternating current (“AC”) power to an AC power output **2114**. An inverter **2116** is coupled to the battery **2113** in order to convert the DC power produced by battery **2113** to AC power. In the embodiment shown in Figure 3, the battery **2113**, inverter **2116** and AC power output **2114** are disposed within an enclosure **2120**.

20 Utilization of the exhaust gas generated in the operation of power unit **2010** is now described with reference to the schematic depiction of an embodiment of the invention in Figure 4. Burner exhaust is directed through a heat conduit **2016** into enclosure **2504** of water purification unit designated generally by numeral **2012**. Heat conduit **2016** is preferably a hose that may be plastic or corrugated metal surrounded by insulation, however  
25 all means of conveying exhaust heat from power unit **2010** to water purification unit **2012** are within the scope of the present invention. The exhaust gas, designated by arrow **2502**, blows across finned heat exchanger **2506**, thereby heating the source water stream **2508** as it travels to still evaporator **2510**. The hot gas **2512** that fills the volume surrounded by insulated enclosure **2504** essentially removes all thermal loss from the still system since the  
30 gas temperature within the insulated cavity is hotter than surface **2514** of the still itself. Thus, there is substantially no heat flow from the still to the ambient environment, and losses on

the order of 75 W for a still of 10 gallon/hour capacity are thereby recovered. A microswitch **2518** senses the connection of hose **2016** coupling hot exhaust to purification unit **2012** so that operation of the unit may account for the influx of hot gas.

In accordance with alternate embodiments of the invention, adding heat to exhaust stream **2502** is within the scope of the invention, whether through addition of a post-burner (not shown) or using electrical power for ohmic heating.

During initial startup of the system, power unit **2010** is activated, providing both electrical power and hot exhaust. Warm-up of water purification unit **2012** is significantly accelerated since finned heat exchanger **2506** is initially below the dew point of the moisture content of the exhaust, since the exhaust contains water as a primary combustion product. All the heat of vaporization of this water content is available to heat source water as the water condenses on the fins of the heat exchanger. The heat of vaporization supplements heating of the fins by convection of hot gas within the still cavity. Heating of the fins by convection continues even after the fins reach the dew point of the exhaust.

In accordance with other embodiments of the present invention, power unit **2010** and water purification unit **2012** may be further integrated by streaming water from the purification unit through the power unit for cooling purposes. The use of source water for cooling presents problems due to the untreated nature of the water. Whereas using the product water requires an added complexity of the system to allow for cooling of the power unit before the purification unit has warmed up to full operating conditions.

Some specific embodiments of the present invention may improve upon the basic design of the liquid ring pump, particularly with respect to increasing overall energy efficiency by reducing frictional losses. A preferred embodiment of the present invention having a fully rotatable housing that provides maximum reduction in frictional loss yet maintains simplicity of design and cost-effectiveness of production is shown in Figures **5A** through **5D**. As can be seen in Figure **5A**, stator **9** is stationary relative to rotor **8**, and comprises an intake **7** and exit **6**. Steam is drawn in at pressure  $P_1$  and passes into rotor chamber **3**. Rotor **8** is off-set from a central axis  $Z$  upon which the rotating housing and the liquid ring pump are centered. As rotor **8** turns about central shaft **14** with rotor bearings **16**, the effective volume of chamber **3** decreases. Steam is thereby compressed to pressure  $P_2$  as it is carried along a rotational path into exit **6**, to be routed to a condenser **200**. Preferably, a

rotatable housing (not shown) rotates with the liquid ring in the liquid ring pump, to reduce energy loss due to friction.

Stator **9** has support structures **26** in the input and output regions, as seen in Figures **5B** and Figure **5C**. The individual vanes **17** of rotor **8** can be seen below the support structures **26** in the top view of stator **9** shown in Figures **5B** and **5C**, as well as the eccentric placement of rotor **8** about the central axis. This particular embodiment of a liquid ring pump is both axially fed and axially ported and may have a vertical, horizontal, or other orientation during operation. Figure **5D** shows yet another view of this embodiment.

Preferably, a liquid ring pump in accordance with the present invention is designed to operate within a fairly narrow range of input and output pressure, such that generally, the system operates in the range of from 5 to 15 psig. System pressure may be regulated using check valves to release steam from chamber **3** of Figure **5A-D**. Improved system performance is preferably achieved by placing exit **6** of the exhaust port at a specific angle of rotation about the rotor axis, wherein the specific angle corresponds to the pressure rise desired for still operation. One embodiment of a specific port opening angle to regulate system pressure is shown in Figure **5B**. Exit **6** is placed at approximately 90 degrees of rotation about the rotor access, allowing steam from chamber **3** to vent. Placing exit **6** at a high angle of rotation about the stator axis would raise the system pressure and lower pump throughput, while placing exit **6** at a lower angle of rotation about the stator axis would result in lower system pressure and increased pump throughput. Choosing the placement of exit **6** to optimize system pressure can yield improved pump efficiency. Further, the placement of exit **6** to maintain system pressure can minimize system complexity by eliminating check valves at the exhaust ports to chamber **3**, thereby providing a simpler, more cost-effective compressor.

An alternative embodiment for a liquid ring pump is shown in Figure **6A** as a schematic diagram. In Figure **6A**, compressor **100** is an example of a possible liquid ring pump with an outer rotatable housing **10** that encloses a single two-channel stator/body **9**, and a rotor **8**, wherein the seal surface between the rotatable housing **10** and stationary stator/body **9** is a cylinder. Two-channel stator/body **9** is kept stationary in reference to a chamber **12** of pump **100** as well as to rotor **8** and rotatable housing **10**, and comprises an intake **7** and an exit **6**. Steam is drawn in at pressure  $P_1$  and passes through an intake orifice

5. When the intake orifice **5** lines up with an intake hole **4** in rotor **8** as the rotor spins around stationary stator **9**, the steam passes through intake hole **4** into a rotor chamber **3**. Rotor **8** is offset from a central axis **Z** so that, as rotor **8** turns, the effective volume of rotor chamber **3** decreases. In this way, steam is compressed to pressure  $P_2$  as it is carried along a rotational path to an exit hole **2** in rotor **8**. As rotor **8** turns, exit hole **2** lines up with an exit orifice **1** of stationary exit **6**, and the steam at pressure  $P_2$  passes through exit orifice **1** into exit **6** to be routed to a condenser **200**. In such an embodiment, rotatable housing **10** rotates with water **19** present in chamber **12** thereby reducing frictional energy losses due to windage. There may also be a small hole **11** present in the housing **10** to permit water **19** to leave and/or enter chamber **12**, thereby controlling the liquid level in the pump. In addition, rotor **8** has multiple vanes **17** that are readily apparent when rotor **8** is viewed from above, as in Figure **6B**. Individual rotor chamber **3**, and individual intake hole **4** and exit hole **2** for each rotor chamber **3**, are also easily seen in this view.

Another alternative embodiment of a liquid ring pump, wherein the interface between rotatable housing **10** and stator **9** is conical rather than cylindrical, is seen in Figure **7A**. In this embodiment, a rotor drive shaft **14** has an end **15** situated upon a bearing **16** that allows rotatable rotor housing **10** to rotate with rotor **8**. Intake **7** and exit **6**, with corresponding intake orifice **5** and exit orifice **1**, are kept stationary with respect to rotor **8** and rotor housing **10**.

In addition, there may be either a conical or axial seal **13** present between stationary sections **6** and **7** and rotor **8**. In the conical embodiment seen most clearly in Figure **7B**, seal **13** thereby separates intake orifice **5** from exit orifice **1** of rotor **8** to prevent leaks. The liquid ring pumps shown in Figures **6** and **7** are both axially fed and radially ported, in contrast with the preferred embodiment of a liquid ring pump, discussed with reference to Figures **5A-5D** (*vide supra*), which is axially fed and axially ported.

During operation, it may be desirable to measure the depth of the liquid ring in the compressor, to optimize performance. In the embodiments herein disclosed, liquid ring pump housing **10** rotates with the liquid ring in the pump, and the temperature of the liquid is typically around 110°C. Methods of measuring ring depth include any one of the usual methods, such as using ultra-sound, radar, floats, fluid conductivity, and optical sensors. Because of the complexities of the rotating housing, use of a capacitive sensor is a preferred

embodiment for this measurement, wherein as the depth of the liquid in the capacitor changes, the capacitance of the capacitor also changes. As shown in Figure 8, a disc-shaped capacitor sensor plate **110** is mounted to the bottom of rotating housing **10**, equidistant from the bottom surface **10A** of rotating housing **10**, and the bottom surface **8A** of rotor **8**. The capacitor is thus defined by housing **10**, rotor **8**, and capacitor sensor **110**. Leads **112** connect the capacitor, from capacitor sensor **110**, through a passageway **53A** in rotating housing shaft **53**, to the secondary **113** of a core transformer, preferably of ferrite (not shown). In one embodiment, the secondary **113** is rotating at the same speed as the capacitor plate, and is in inductive communication with the primary of the ferrite core transformer.

The primary winding **114** is stationary, and signals to and from the level-measuring capacitor are communicated through the transformer, in this way enabling depth information to be transmitted from a rotating position to a stationary position. Capacitance is measure by determining the LC resonance of the capacitor (C) with the inductance (L) of the transformer secondary. In a preferred embodiment, an LC oscillator circuit is constructed and the oscillation frequency is used as a measure of the capacitance.

Alternatively, in another particular embodiment in accordance with the invention, it can be envisioned that a regenerative blower might be used in place of a liquid ring pump for compressor **100**. An example of a possible regenerative blower that could be used instead of a liquid ring pump is the commercially available REGENAIR® R4 Series by GAST (e.g. models R4110-2/R4310A-2 et seq.), capable of operating at 52" H<sub>2</sub>O maximum pressure, 92 cfm open flow, or 48" H<sub>2</sub>O maximum pressure, 88 cfm open flow, respectively. See Appendix A, incorporated by reference herein.

To prevent contaminated liquid droplets from being entrained and carried along with vapor to condenser **200**, pump **100** may be designed as shown in the alternative embodiment of Figure 9, for example. In such an embodiment, the liquid ring pump is within the head space of the evaporator/condenser, and mist is eliminated as rotating housing **10** rotates, wherein the rotation creates a cyclone effect, flinging mist and water droplets off by centrifugal force to collide with the still housing and run down to the water in the sump. There may also be fins **18** extending from the outside of rotating housing **10** to enhance circulation and rotation of vapor in the annular space between rotating housing **10** and fixed housing **25**. A steam exit **22** is provided for passage of steam to condenser **200**.

In a preferred embodiment, there may also be an actuator **150**, such as a motor, for driving compressor/pump **100**, as shown in Figure **10**. Motor **150** receives power from power source **800** (shown in Figure **1A**). In the particular embodiment shown in Figures **10** and **11**, the motor rotor/magnets **37** are hermetically sealed inside the pressure and fluid boundary of the system, and the motor can **27** and motor stator/windings **38** are located outside the main pressure system envelope. A single continuous shaft **14** spans the length from motor **150** to pump **100**, about which sit bearings **16**, to enable rotation of motor rotor **37** and pump rotor **8**. Use of a hermetically sealed motor and continuous shaft eliminates the need for a sealed shaft penetration of the pressure boundary. In addition, the motor is maintained at a constant temperature by the surrounding saturated steam and circulation of liquid intake **39** about motor stator **38** (see Figure **14A**, *infra*). Heat generated by the motor is therefore transferred into the system, reducing the overall heat input required to maintain the temperature.

In one embodiment, motor **150** is a motor of the type designed to be run in steam and water, eliminating the need for shaft couplings and mechanical seals, thereby reducing drag and complexity in the mechanical components, and simultaneously allowing better recovery of motor power loss. In such an embodiment, motor rotor **37** (see Figure **10**) is made of laminations. To protect against rust, the laminations may be made of steel, and are protected by plasma coatings, silicone coatings, powder coatings or the laminations and magnets may be plated with nickel.

In a more preferred embodiment, motor rotor **37** is a solid material rotor such as pure iron or stainless steel, for example, a high-chromium content steel such as 446 stainless steel. The iron or steel rotors **37** may be nickel-plated, as may be magnets **37A**. Pure iron rotors have the best magnetic properties, and improved torque relative to laminated rotors. Alternatively, solid stainless steel rotors with nickel-plated magnets may be used. Preferably the stainless steel has a high chromium content, thereby creating a coating of chrome oxide on the surface of rotor **37**, which protects the iron content in the rotor from rust. As with pure iron rotors, stainless steel rotors also have improved torque over laminated rotors.

In yet another embodiment, the high-chromium content stainless steel rotor may be passivated to remove surface iron, creating a thick chromium oxide coating for enhanced corrosion protection. Other applied coatings may be used to aid in corrosion resistance. In

addition, the nickel-plated magnets may be curved surface magnets, which will further increase motor torque and reduce manufacturing costs.

As shown in Figure 10, motor housing 27 contains motor 150 with motor stator/windings 38. Motor can 28 hermetically seals motor rotor 37, motor magnets 37A, and motor and pump rotor continuous drive shaft 14 within the fluid/pressure envelope of the system. Fixed housing 25 encloses non-rotating valve-plate 33, and pump rotor 8 having multiple rotor vanes 17, rotor bearings 16, and a liquid ring 19 (see Figures 6A or 9), typically water, that rotates with rotating housing 10. A drain (not shown) on outer housing 25 prevents over filling of the liquid ring pump stationary housing.

A lower reservoir 30 containing a level of liquid, connects to a drain/fill fluid line (not shown), and houses siphon pump 32 and rotating housing bearings 52 about rotating housing shaft 53. Siphon pump 32 redirects liquid, preferably water, from lower reservoir 31 up siphon pump line 35 and continuing through siphon feed line 36 into chamber 12. As rotor 8 and liquid ring 19 rotate, water droplets 20 are flung by centrifugal force outwards, through a liquid ring overflow opening (not shown), against fixed housing 25, and then run down fixed housing wall 25 and back into lower reservoir 30.

Figure 12A shows an embodiment in accordance with the present invention of external fixed housing 25, external motor housing 27, exhaust and intake manifolds 6 and 7, respectively, and motor can 28. Figure 12B is a cross-sectional view of the embodiment depicted in Figure 12A. External motor housing 27, external housing 25, and lower reservoir 30, are visible, including rotating housing bearings 52. In addition, a motor with motor rotor 37, motor stator 38, and single continuous rotor shaft 14 and rotor vanes 17 are also visible.

Similarly, Figure 12C shows a cross-sectional view of the same embodiment as seen in Figures 12A and 12B, but through a different plane. Now, siphon pump 32, with siphon pump line 35 and siphon feed line 36 connecting into chamber 12, can be readily seen within lower reservoir 30.

A detailed view of siphon pump 32 can be seen in Figure 13, a cross-sectional view of lower reservoir 30. Figure 13 shows lower reservoir 30, within which can be seen rotating housing bearings 52 and a cut-away view of siphon pump 32, siphon pump line 35, siphon feed line 36 and chamber 12. In operation, siphon pump 32 draws water from lower reservoir 30, pumps the water up through siphon pump line 35 to siphon feed line 36, and

thereby back into chamber **12**. With reference to Figure **10**, embodiments of the invention that transfer fluid from lower reservoir **30** to chamber **12** may utilize one or more baffles in lower reservoir **30**, preferably attached to the stationary, exterior housing **25**. The baffles, which preferably may be radial in configuration, disrupt the flow of fluid induced by the rotation of housing **10**, to prevent loss of siphon in siphon pump **32**, thereby maintaining better siphon flow and enabling prime if siphon is lost.

Another specific embodiment of the present invention is designed to improve overall energy efficiency of the system, and is shown in Figure **14A**. A system in accordance with this particular embodiment has cold liquid intake **39** flowing through pump intake **00**, continuing through exchanger **400**. Pump **00** is typically a diaphragm positive-displacement pump, which is self-priming when the system is not pressurized – i.e.,  $P$  inside the system equals  $P$  outside. In a preferred embodiment, pump **00** may also have a loop feedback configuration, with air vent **01**, to help prime pump **00** upon start-up, or more particularly, to re-prime the operating system, under pressure, if the prime is lost, as would happen if the source hose were removed from the liquid source container.

From exchanger **400**, the intake line may continue in a cooling loop about motor **150**, and then continue into core evaporator/condenser **600** wherein condenser **200** has a top core plate **48** and a bottom core plate **50**. Within core evaporator/condenser **600** may be multiple parallel tubes **49**, typically made of copper-nickel alloy or other heat-transferable material, having head manifold openings **56** to allow core tubes **49** to communicate with head **300**, and having sump manifold openings **55** to allow tubes **49** to communicate with sump **500**. Core tubes **49** are the heat exchange surface through which the latent heat of evaporation is transferred in the evaporation/condensation cycle. The rate at which heat can be exchanged between the condensing steam, outside the tubes, and evaporating water, inside the tubes, is a key factor in output rate and efficiency. If the thermal resistance of the heat exchange surface is low, better heat exchange occurs and output volume and efficiency increases. Any air impinged against the condensing surface becomes an insulator that inhibits transfer of heat. To prevent this, any air present in the system is continuously vented out of the system, via, for example, air vent **01**, volatile mixer **23**, or other venting outlets as required.

Heat transfer may also be adversely affected when water forms sheets as it condenses and coats the exterior of the tubes as it runs down to the bottom of the condenser chamber, a

phenomenon known as “skinning.” The extent to which the water “skins” on the surface of the condenser is determined largely by the surface energy (hydrophobicity) of the heat transfer surface. In an embodiment of the present invention, hydrophobic coatings may be applied to cause condensing water to bead-up rather than skin, thereby leaving more of the heat transfer surface exposed for efficient heat transfer. Examples of suitable hydrophobic coatings include a coating manufactured by Ocular Technologies, or any other hydrophobic coating that imposes little to no thermal resistance itself.

Steam **21** from the condenser section **600C** of evaporator/condenser **600** may also feed into a volatile mixer **23** where volatile gases may be released from the system.

The system maintains a constant blowdown water flow to prevent scaling and other accumulation in the system. Water level **19** in head chamber **300** is adjusted through a feedback control loop using level sensor L1, valve V1, and source pump **00**, to maintain proper water flow through the blowdown stream **43**. The three-way source pump fill valve **29** is set to pump water into sump **500**, which causes water level **19** in head chamber **300** to rise. As liquid level **19** rises in head chamber **300**, liquid overflows past a dam-like barrier **302** into blowdown control chamber **301** containing blowdown level sensor L1. As required, blowdown valve V1 is controlled to allow water flow from blowdown control chamber **301** through heat exchanger **400**, to extract heat and cool blowdown stream **43**, and flow out valve V1, through volatile mixer **23** allowing cooling of hot gases and steam **21** from the evaporator section **600B**, and then completing the blowdown stream, out to waste **43A**.

The system also maintains proper product flow. Product level **502** builds up in condenser chamber **600C**, and enters into product control chamber **501**, where product level sensor L2 is housed. Using a feedback control loop with level sensor L2 and valve V2, product stream **41** is controlled to flow from product control chamber **501** through heat exchanger **400**, to extract heat and cool product stream **41**, then through valve V2 and on out to complete the product stream as product water outlet **41A**.

The system may preferably be configured to maintain proper liquid ring pump water level by the use of a liquid recovery system to replenish liquid loss. There are several ways that liquid from the ring pump may be depleted during system operation, including leakage into lower reservoir **30**, expulsion through exhaust port **6**, and evaporation. The leakage and expulsion losses can be large depending on operational parameters, such as the speed of

rotation and liquid ring pump throughput. These leakage and expulsion losses could require total replacement of the fluid in the pump several times per hour. The evaporation loss is typically small.

Liquid level in the ring pump can be maintained by adding additional source water, product water, or preferably by re-circulating liquid water lost from the liquid ring pump for improved system efficiency. In one preferred embodiment, the liquid level in the ring pump is primarily maintained by re-circulation of the liquid accumulated in lower reservoir **30** in Figure **14A**. Liquid can accumulate in lower reservoir **30** from leakage from the liquid ring pump and from fluid expelled in exhaust **57**, captured in mist eliminator **58** and pumped to lower reservoir **30**. Alternatively, fluid expelled in exhaust **57** and captured in mist eliminator **58** can be returned via the liquid ring pump exhaust port. Fluid accumulated in lower reservoir **30** can be re-circulated by one of several pumping mechanisms. One preferred method is to use a siphon pump **32** (described above) as shown in Figures **10** and **12C**.

A minimum depth of water is preferably maintained in the lower reservoir for the siphon pump **32** to perform properly. In one preferred embodiment, liquid ring pump control chamber **101**, which houses liquid ring pump level sensor **L3** can be used to control the liquid ring pump level and control the level of water in the lower reservoir **30**, as shown in Figure **14A**. Liquid ring pump control chamber **101** is fluidly connected to liquid ring pump **100** and lower reservoir **30**. Liquid ring pump **100** is connected to the three-way source fill valve **29**, which is set to open when the liquid ring pump requires more water and it is also connected to the liquid ring pump drain valve **V3**, which opens when it is required to drain water from liquid ring pump **100** into blowdown stream **43**.

If re-circulated water from lower reservoir **30** is not primarily used to maintain the fluid level in the liquid ring pump, then either cold source water or product water could be used. In the event source water were used, the introduction of cold water (which could be approximately 85 degrees C colder than system temperature) to the liquid ring pump would decrease system efficiency or alternatively the use of a pre-heater for such cold source water would increase the energy budget of the system. Alternatively, the use of product water, while not adversely affecting system temperature, could decrease production level and, thus,

also lead to system inefficiency. At startup, the initial fluid level for the liquid ring pump is preferably supplied from source water.

In one embodiment, the start-up time may be reduced by using an external connecting valve **43AA** between source **39** and blowdown **43** fluid lines, located adjacent to heat exchanger **400**, on the cold side, as shown in Figure **14B**. To determine the level of fluid in evaporator head **300** during the initial fill, connecting valve **43** would be open, blowdown valve **BV** would be closed, and fluid would be pumped into the system through source line **39**. Connecting blowdown **43** and source **39** lines results in equal fluid height in the blowdown level sensor housing **301** and evaporator head **300**, thereby permitting a determination of fluid level in evaporator head **300** and enabling the evaporator to be filled to the minimum required level at startup. Using the minimum level required shortens initial warm-up time and prevents spill-over from the evaporator head **300** through the liquid ring pump **100** to the condenser **600** when the liquid ring pump **100** starts (see Figure **14A**).

The concentration of solids in blowdown stream **43** may be monitored and controlled to prevent precipitation of materials from solution and thus clogging of the system. Also during start-up, circulating pump **43BB** can circulate water through heat exchanger **400** to pre-heat the heat exchanger to the proper temperature for normal operation. A conductivity sensor (not shown) may be used to determine total dissolved solid (TDS) content by measuring the electrical conductivity of the fluid. In a particular embodiment, the sensor is an inductive sensor, whereby no electrically conductive material is in contact with the fluid stream. If the TDS content in blowdown stream **43** rises above a prescribed level, for example, during distillation of sea water, the fluid source feed rate is increased. Increasing the fluid source feed rate will increase the rate of blowdown stream **43**, because distilled water production changes only slightly as a function of fluid feed rate, and an increased blowdown stream rate results in reduced concentration of TDS, thereby maintaining overall efficiency and productivity of the system.

As discussed in relationship to Figure **14A**, fluid control is achieved by using level sensors and variable flow valves in a feedback configuration. Optimal operation of the still requires total fluid flow in to closely match total fluid flow out. Maintaining fluid levels in the still at near constant levels accomplishes this requirement. In a particular embodiment, the sensors are capacitive level sensors, a particularly robust sensor for measuring fluid

levels. Capacitive level sensors have no moving parts and are insensitive to fouling, and manufacture is simple and inexpensive. Opening of a variable flow valve is controlled by the level of liquid measured by the capacitive level sensor, whereby the fluid level is adjusted at the level sensor location. A rising fluid level causes the valve to open more, increasing flow out of the sensor volume. Conversely, a falling fluid level causes the valve to close more, decreasing flow out of the sensor volume.

Flow rate through the variable flow control valves and from the input pump can be determined using an *in-situ* calibration technique. The level sensors and associated level sensor volume can be used to determine the fill or empty rate of the sensor volume. By appropriately configuring the control valves, the flow rate calibration of each valve and also of the source pump can be determined.

In a particular embodiment of the invention, a valve block (not shown) may be utilized to consolidate all control valves for the system into a single part, which may be integrated with the fluid flow manifold. A control system comprising a sensor for total dissolved solids and blowdown stream may also be incorporated, as well as a float valve or other device for controlling the height/level of liquid in the head.

As shown in Figure 14A, there is additionally a steam flow line 22 from head 300 to compressor 100, a steam outlet 57 for diverting steam to condenser 200, a hot product line 41 from condenser 200 leading through exchanger 400, which also allows for collection of hot purified condensed product 502, and a line (not shown) for diverting hot product to compressor 100 to allow adjustment of water level to keep it constant. There may also be a drain line (not shown), for when the system is shut down.

Further, there may be a heater 900 with heating element 60 for heating cold liquid to boiling at start-up, and for maintaining sufficient heat during operation of the still to continuously convert liquid to steam. In one embodiment of the invention, the distillation system may operate at steady-state without thermal input from the heater 900 after system start up. Alternatively, a second heater (not shown) may be used to maintain sufficient heat during operation; the heater may run continuously, in a pulsed mode, or be controlled by a controller.

In one particular embodiment, evaporator/condenser 600 is evaporator/condenser 600A having elastomer tube and shell seals 54A and 54B for core tubes 49, as shown in

Figure 15, replacing end plates 48 and 50, respectively, of Figure 14A. Such elastomer tube and shell seals are exemplified in U.S. Patent No. 4,520,868, which is hereby incorporated by reference herein. Tool-less clamp-on seals 59 external to evaporator/condenser 600A allow easy access for cleaning and repair, and replacement of core tubes 49, if needed.

Externally removable fittings 47 may be used to couple fluid condenser steam inlet port 70, liquid product outlet port 66, evaporator steam outlet port 69, blowdown stream outlet port 65, liquid input port 64, and volatile port 67 to evaporator/condenser 600A. In this particular embodiment, a thick film heater 900A may be used to heat liquid in the sump, replacing heater 900 and heating element 60 (see Figure 14A).

In yet another particular embodiment in accordance with the invention there may be an evaporator/condenser 650, as shown in Figures 16A and 16B, in place of core 600. As seen in Figure 16A, evaporator/condenser 650 is a flat evaporator/condenser and contains multiple parallel core layers 92 and 94, typically made of copper-nickel alloy or other heat-transferable material, with rib sections 90 creating channels 95 and 97 for directing steam and condensed liquid flow. Steam intake 7A and product exit 6A manifolds (as well as dirty intake and volatile exit manifolds, not shown) connect via a fluid interface to liquid ring pump/compressor 100. Bolts 88 secure core evaporator/condenser 650 to brackets of external housing 25. In operation, every alternating horizontal (as shown in Figures 16A and 16B) row 92 and 94 comprises evaporator channels 95 and condenser channels 97, such that the two functions never overlap on any given layer. Figure 16B, a detail of Figure 16A, shows more clearly how the combined condenser/evaporator manifolding works. As indicated, rows 92 do not interact with rows 94, they are closed off to each other, thereby separating the functions of evaporation and condensation in the horizontal core layers.

In addition, another particular embodiment in accordance with the invention may include fluid distribution manifold 675, shown in Figures 17A through 17D. Figure 17A shows one face of the pump side of one particular embodiment of a fluid distribution manifold 675. Input, in the form of raw source feed, flows through port 64, and blowdown stream (output) flows through port 65. Additional output in the form of product flows through port 66, while port/chamber 67 provides the vent for volatiles (output) and port 68 provides the drain (output) for liquid ring pump. Figure 17B shows the other face of the pump side of the same particular embodiment of fluid distribution manifold 675.

Port/chamber **67**, for output of volatiles, is apparent, as is the drain **68** for a liquid ring pump. In this view of this particular embodiment, a condenser steam mist eliminator chamber **71** is visible, as is a mist collector and drain area **73**.

Figure **17C** shows one face of the evaporator/condenser side of the same particular embodiment of fluid distribution manifold **675**. Raw source feed port **64**, as well as  
 5 blowdown passage ports **65** and product passage ports **66**, are readily visible in this view. In addition, evaporator steam passage port **69** and condenser steam passage port **70** can be seen.

Finally, Figure **17D** shows the other face of the evaporator/condenser side of the same particular embodiment of fluid distribution manifold **675**. Again blowdown passage  
 10 port **65** is visible, as is liquid ring pump drain port **68**, a second condenser steam mist eliminator **71**, evaporator steam mist eliminator **72**, and mist collector and drain area **73**. Also, a sump level control chamber can be seen in this view, along with a product level control chamber **75** and a liquid ring pump supply feed **76**.

In such a particular embodiment, a fluid distribution manifold **675** is capable of  
 15 eliminating most plumbing in a liquid purification system, advantageously incorporating various functionality in one unit, including flow regulation, mist removal, and pressure regulation, thereby simplifying manufacture and significantly reducing overall component parts. The core plates and manifolding may be made of, for example, plastic, metal, or ceramic plates, or any other non-corrosive material capable of withstanding high temperature  
 20 and pressure. Methods of manufacture for the core plates and manifolding include brazing and over-molding.

Figures **18A** and **18B** show couplers that allow fluid interfacing throughout the system in a particular embodiment. For example, there may be a floating fluid interface between exchanger **400** and intake/exhaust ports **7** and **6** seen in Figure **12A**. Figure **18A**  
 25 shows such a fitting **61** that can be welded to heat exchanger ports (not shown), wherein fitting **61** connects to fluid interface **62** which is in turn in communication with the fluid distribution manifold. Figure **18A** shows a sectional view across line A—A (see Figure **18B**). Fitting **61** has the ability to float to compensate for shifts in registration, possibly caused by temperature or manufacturing variations. Sealing is accomplished by o-ring **63**.  
 30 As can be seen in the view depicted in Figure **18B**, o-ring seal **63**, upon rotation of line A—

A 90° about a central axis, fitting **61** and fluid interface **62** lock together to make a fluid interface connection.

For either core **600** having core tubes **49**, or core **650** having parallel core layers **92** and **94**, the geometry of the core tubing or layer channels may be cylindrical, square, rectangular, and the like. In still another specific embodiment in accordance with the present invention, core configurations may be selected to increase the net phase change rate of the liquid, and may include core inserts, which are more fully detailed in U.S. Patent Application Serial No. 10/636,303 filed August 7, 2003 entitled "Method and Apparatus for Phase Change Enhancement," the contents of which are hereby incorporated by reference herein.

Scale control may be achieved using chemical treatments such as with polyphosphates or polyaspartates, via plasma coating of appropriate components through the use of galvanic or electrochemical processes, by treatment with acids such as an organic acid, or through the use of electric and/or magnetic fields.

Other particular embodiments of the present invention may advantageously improve energy efficiency of the overall system by including, for example, highly efficient heat exchangers **400A** and **400B** as shown in Figures **19A** and **19B**, wherein such heat exchangers capitalize on available systemic and heat sources. In one particular embodiment, heat from at least one of a plurality of sources passes through a multi-line heat exchanger **400A** such as depicted in Figure **19A**, wherein a series of two-channel heat exchangers such as **38**, **40**, **42**, and **44** are plumbed to produce a multi-line effect. Note that in the particular multi-line heat exchanger embodiment shown in Figure **19A**, the flow of cold intake **39** passes through all heat exchanger units **38**, **40**, **42**, and **44**; one heat source, for example hot product **41**, flows through heat exchanger units **38** and **42**; and another heat source, for example hot blowdown stream **43**, flows through heat exchange units **40** and **44**. In this way, multiple heat sources can be used to exchange with the cold intake flow **39**.

Alternatively, a single multi-channel heat exchanger **400B** such as depicted in Figure **19B** may be used. In this particular embodiment, cold intake **39**, and heat sources such as hot product **41** and hot blowdown stream **43**, for example, flow through exchanger **400B** simultaneously, but in opposite directions, thereby enabling heat exchange with cold intake **39** from both heat sources **41** and **43** within a single heat exchanger **400B**. Heat sources for heat exchanger **400** include product stream **41** and blowdown stream **43**. Another possible

heat source for the heat exchanger **400** is radiative heat produced by steam pump drive motor **150**, such as by the motor windings, when the embodiment utilizes an external drive motor. As discussed above, tube bundle heat exchanger technology detailed in U.S. Patent No. 4,520, 868 may be utilized for the heat exchangers in accordance with the present invention, wherein elastomeric end plates may be used to seal the tubes in a fixed orientation, in place of metal or otherwise inelastic end plates soldered or brazed to the heat exchanger tubes.

As discussed above with respect to Figures **1A** and **1B**, the power source **800** may be, for example, an IC generator or a Stirling engine generator. In one embodiment, the radiative heat produced by the generator may be used to heat the intake stream, wherein the radiative heat produced by the generator is directed to heat exchanger **400**. Such a heat exchanger would optimally be positioned at the hot side of a three-channel heat exchanger, such as shown in Figure **19B**, where source liquid **39** enters evaporator **600**. Figure **14A** or Figure **4** (element **2506**) also show such a heat exchanger that could be utilized with exhaust heat in one of the channels.

If an external drive shaft motor is utilized, the overall system may employ an additional “cold” fluid pump of the gear-, diaphragm-, or “ram-” pump variety inline with cold intake line. In a particular embodiment, such a pump will be driven off the same rotor drive shaft as the liquid ring pump. Other particular embodiments of the present invention may also be envisioned without a fluid intake pump, whereby a gravity-feed mechanism or creation of a vacuum is used to drive the fluid through the system.

In another particular embodiment, sump **500** may employ a pre-heater or supplemental heater, wherein a switch and temperature sensor with relay monitor is employed to regulate heat input and temperature of the water in the sump. Other fluid reservoirs may also contain temperature sensors. For example, a temperature sensor in the sump could be used to determine optimum conditions for the initiation of distillation as the still heats up. Temperature sensors may also be employed to detect changes in water temperature, thereby allowing adjustment of fluid flow rates to maintain overall still production.

In one embodiment, shown in Figure **20**, the evaporator and condenser pressures are measured, to assess overall system performance and/or provide data to a control system. To avoid the use of expensive sensors that would be required to withstand the elevated

temperatures of condenser/evaporator **600**, pressure sensors **P<sub>E</sub>** and **P<sub>C</sub>** are mounted on fluid lines between the cold side of heat exchanger **400** and corresponding control valves **V<sub>E</sub>** and **V<sub>C</sub>**. To avoid measuring a pressure less than the actual pressure of the system, which would occur when fluid is flowing for pressure sensors located at this position, the control valve  
 5 would be closed momentarily to stop flow. During the “no-flow” period, pressure will be constant from the control valve back to the evaporator or condenser, enabling accurate measurement of the system pressure. No adverse effects on still performance will occur from these short “no-flow” periods.

Still another embodiment of the present invention is designed to increase the purity of  
 10 the final purified liquid product by incorporating a filtering mechanism within intake **00**, as shown in Figure **21A**. A multi unit flip-filter **80**, having a pivot joint **82** joining at least two filter units **81** and **83**, is situated within a filter housing **80A** which directs liquid through filter units **81** and **83** and facilitates rotation of filter units **81** and **83** about central pivot joint **82**. As shown, blowdown stream **43** passes through flip-filter unit **81**, while intake liquid  
 15 stream **39** simultaneously flows from intake **00** through flip-filter unit **83** en route to purification. After some interval a flip-filter switch (not shown), rotates flip-filter **80** around its central axis, shown by the dotted line, at flip-filter pivot joint **82**, such that filter unit **83**, now fouled with contaminants filtered from dirty intake liquid, is backwashed by blowdown stream **43**, and filter unit **81** becomes the filter unit which filters intake liquid stream **39**. In  
 20 such an embodiment, o-ring gaskets **81A** and **83A** may be utilized as seals between filter units **81** and **83** and the liquid flow routes of blow-down stream **43** and intake liquid stream **39**, respectively.

In another embodiment, the multi-unit flip filter may be a multi-sected circular filter **80B**, shown schematically in Figure **21B**. Multi unit flip-filter **80B**, having a pivot point **82B**  
 25 about which multiple flip-filter units such as **81B** and **83B** pivot, may also be situated within filter housing **80C** that directs liquid flow through individual filter units **81B** and **83B** and facilitates rotation of filter **80B** about pivot point **82B**. As shown, blowdown stream **43** passing through one flip-filter unit **81B**, while intake liquid stream **39** simultaneously flows from intake **00** through flip-filter unit **83B** en route to purification. As in Figure **21B**, a flip-  
 30 filter switch (not shown), rotates flip-filter **80B** around its central axis, shown by the dotted line, at flip-filter pivot point **82B**, such that filter unit **83B**, now fouled with contaminants

filtered from dirty intake liquid, is backwashed by blowdown stream **43**, and filter unit **81B** becomes the filter unit which filters intake liquid stream **39**. A series of seals, as indicated by **81B-1** and **83B-1**, are utilized between individual filter units **81B** and **83B**, to partition blowdown stream **43** flowing through one filter section, from intake liquid stream **39** flowing through another filter section.

Alternatively, a manual valve **85**, such as shown schematically in Figure **22**, could be employed to manually change the direction of water flow. Such a valve allows use of, for example, blowdown stream **43** to continuously clean one unit of each flip-filter, and with a single operation effectively switches which unit is being filtered and which unit is being back-washed, thereby back-washing filter units **81** or **83** without the need to actually flip filter **80** itself. As can be seen in Figure **22**, in one particular embodiment when valve **85** is in position **A**, filter unit **81** is filtering intake liquid **39**, and filter unit **83** is being back-washed with blowdown stream **43**. Upon switching valve **85** to position **B**, filter unit **81** is now being backwashed by blowdown stream **43**, and filter unit **83** is now filtering input liquid **39**.

In another particular embodiment, not shown, there may be an external system including a holding tank with a pump for waste discharge, if circumstances require.

The particular embodiments described above generally operate above atmospheric pressure, typically around 10 psig. Such a system advantageously provides higher steam density at the higher pressure, thereby allowing more steam to be pumped through a positive displacement pump than at lower pressure. The resulting higher throughput provides overall improved system efficiency. Further, the higher throughput and higher system pressure reduces the power needed for compressor **100**, and eliminates the need for two additional pumps – one for pumping condensed product **41** and another for pumping blowdown stream **43**. Overall construction is simplified, as many shapes withstand internal pressure better than external pressure. Importantly, operating at super-atmospheric pressure reduces the impact of minor leaks on the overall efficiency and performance. Non-condensable gases such as air inhibit the condensation process, and would be magnified at sub-atmospheric pressure, where minor leaks would serve to suck in air, something which will not occur in a system operating at super-atmospheric pressure.

When embodiments of the invention operate above atmospheric pressure, the use of a novel backpressure regulation may serve to control the operating pressure of the system. Figs. **23A** and **23B** depict views of a backpressure regulator consistent with an embodiment of the invention. The backpressure regulator **1100** has a vessel **1150** containing an orifice **1110**. One side of the orifice is connected to a pressurized conduit of a system (e.g., the outlet of a compressor in a vapor compression distillation system) which may be exposed to the fluctuating elevated pressure. The other side of the orifice terminates in a port **1170**. The port **1170** is covered by a movable stop **1130**, in the shape of a ball. The stop **1130** is retained to an arm **1120** by means of a retainer **1160** at a fixed distance from a pivot pin **1140**. The arm **1120** is attached by a hinge via the pivot pin **1140** to a point with a fixed relation to the orifice port **1170**. The arm **1120** includes a counter mass **1180** suspended from the arm that is movable along an axis **1190** such that the distance between the counter mass **1180** and the pivot pin **1140** may be varied. In the embodiment shown in Figure **23A**, the axial direction of the orifice **1110** is perpendicular to the direction of the gravitational vector **1195**. The backpressure regulator may also include a housing, which prevents foreign matter from entering the regulator and interfering with the function of the internal components.

In operating the embodiment shown in Figs. **23A** and **23B**, the arm **1120** maintains a horizontal position with respect to the direction of gravity **1195** when the pressure in the pressurized conduit is below a given set point; this arm position, in this embodiment, is known as the closed position, and corresponds to the stop **1130** covering the port **1170**. When the pressure in the conduit exceeds the set point, a force acts on the stop **1130**, which results in a torque acting around the pivot pin **1140**. The torque acts to rotate the arm **1120** around the pivot pin **1140** in a counter-clockwise direction, causing the arm to move away from its closed position and exposing the port **1170**, which allows fluids to escape from the orifice **1110**. When the pressure in the conduit is relieved below the set point, the force of gas is no longer sufficient to keep the arm **1120** away from its closed position; thus, the arm **1120** returns to the closed position, and the stop **1130** covers the port **1170**.

In the embodiment of Figs. **23A** and **23B**, the arm **1120** acts as a lever in creating adjustable moments and serves to multiply the force applied by the counter mass **1180** through the stop **1130** to the port **1170**. This force multiplication reduces the weight needed

to close the orifice **1110** as opposed to a design where the stop **1130** alone acts vertically on top of the orifice **1110**, as in a pressure cooker. Thus a large port size, to promote expedited venting from a pressurized conduit, may be covered by a relatively lightweight, large-sized stop, the counter mass acting to adjust the desired set point; less design effort may be expended in choosing specific port sizes and stop properties. The addition of an axis **1190** for adjusting the position of the counter mass **1180**, in the present embodiment, allows for changes in the multiplier ratio. As the counter mass **1180** is moved to a position closer to the pivot pin **1140**, the multiplier ratio is reduced, creating a lower closing force. If the counter mass **1180** is moved farther from the pivot pin **1140**, the multiplier ratio is increased, hence increasing the closing force. Therefore, the position of the counter mass **1180** effectively acts to adjust the set point of the backpressure regulator.

Adjustment of the backpressure regulator set point may be useful, when the backpressure regulator is utilized in systems at higher altitudes. When the atmospheric pressure is lower, the system operating pressure is commensurately lower. As a result, the temperature of the distillation apparatus is lowered, which may adversely affect system performance. As well, such adjustment allows one to identify set points for the backpressure regulator that are desired by the end user. The use of a counter mass to apply the closing force may also lower cost of the backpressure regulator and reduce component fatigue. In a particular embodiment of the invention, the adjustable counter mass is designed to allow a range of set points with a lowest set point substantially less than or equal to 10 psig. and a highest set point substantially greater than or equal to 17 psig. Thus embodiments of the invention allow for precise system pressure regulation, unlike devices which act simply as safety relief valves.

In another embodiment of the invention shown in Figs. **24A** and **24B**, the orifice **1210** is configured such that the port **1270** is oriented vertically with respect to the direction of gravity **1295**. Thus other embodiments of the invention may accommodate any orifice orientation while maintaining the use of an adjustable counter mass.

In an embodiment of the invention shown in Figs. **23A**, **23B**, and **25**, the vessel **1150** includes a drain orifice **1115**. Since the backpressure regulator **1100** may operate within a bounded region **1310** of a large system **1320**, the drain orifice **1115** acts as a pathway to release fluids that are purged from the pressurized conduit **1340** through orifice **1110** into the

bounded region **1310**. The drain orifice **1115** may connect the bounded region **1310** to another area of the larger system, or to the external environment **1330**. In addition, the build-up of gases in the bounded region **1310** may result in condensation of such gases. Also, gases purged through the orifice **1110** may be entrained with droplets of liquid that may accumulate in the bounded region **1310**. Thus the drain orifice **1115** may also be used to purge any build up of condensables that accumulate in the bounded region **1310**; the condensables may also be released from the bounded region using a separate orifice **1350**.

The backpressure regulator may be configured to allow a small leakage rate below the set point in order to purge the build up of volatile gases that act to insulate heat exchange and suppress boiling in a system; the regulator is designed, however, to allow pressure to build in the pressurized conduit despite this small leakage. In an embodiment of the invention, release of volatile components from a pressurized conduit, below the set point of the backpressure regulator, may also be achieved through a specifically-designed leak vent while the arm of the backpressure regulator is in the closed position. The leak vent is configured to allow a certain leakage rate from the port or the orifice while the pressure in the conduit is below the set point. Such leak vent may be designed by a variety of means known to those skilled in the art. Non-limiting examples include specific positioning of the stop and port to allow a small opening while the arm is in the closed position; designing the port such that a small opening, not coverable by the stop, is always exposed; specifying a particular rigid, non-compliant seal configuration between the stop and port when the arm is in the closed position; and configuring the orifice leading to the port to have a small opening to allow leakage of fluids.

In a particular embodiment of the invention directed toward the leakage of volatiles below the set point of the backpressure regulator, the port **1410** has a small notch **1420** as shown in Figure **26A** and the close-up of region **C** of Figure **26A** depicted in Figure **26B**. Thus, when a stop is in contact with the port **1410**, when the arm of the backpressure regulator is in the closed position, a leak vent is present that allows a small leakage through notch **1420**. In another particular embodiment of the invention, orifice **1510** has a small opening **1520**, as depicted in Figure **27A** and blow up of region **E** of Figure **27A** depicted in Figure **27B**. The opening **1520** is configured such that a leak vent is present when the stop covers the port **1510** since fluids may leak through the opening **1520**.

Various features of a backpressure regulator consistent with embodiments of the invention may be altered or modified. For example, stops to be used with backpressure regulators may have any shape, size, or mass consistent with desired operating conditions, such stops need not be ball-shaped as shown in some embodiments of the invention  
5 discussed herein. As well, stops of different weight but similar sizes may be utilized with the retainer to alter the set point of the regulator. Similarly, counter masses of different sizes, shapes and masses may be utilized with embodiments of the invention as long as they are accommodated by the axis and arm configurations (compare **1180** in Figs. **23A** and **23B** with **1280** in Figs. **24A** and **24B**); such counter masses may be attached and oriented relative to  
10 the arm by any of a variety of techniques apparent to those skilled in the art. The pivot pin placement need not be positioned as shown in Figs. **23** and **24**, but may be positioned wherever advantageous to provide the mechanical advantage required to achieve a particular pressure set point.

Embodiments of the invention may optionally utilize the drain orifice feature  
15 described earlier. Also, embodiments of the invention may not utilize the counter mass force adjustment feature, relying on the specific properties of a stop to provide the set point for the backpressure regulator.

Other embodiments of the invention may not utilize a vessel, but rely on orifices that are intrinsically part of the system. In such instances, the backpressure regulator arm may be  
20 directly attached to a portion of the system such that the arm, stop, and counter mass are appropriately oriented for the operation of the regulator.

As described above, various embodiments of this invention may advantageously provide a low-cost, easily maintained, highly efficient, portable, and failsafe liquid purification system that can provide a reliable source of drinking water for use in all  
25 environments regardless of initial water quality. The system of the present invention is intended to produce a continuous stream of potable water, for drinking or medical applications, for example, on a personal or limited community scale using a portable power source and moderate power budget. As an example, at the desired efficiency ratio, it is envisioned that the present system may be utilized to produce approximately 10 gallons of  
30 water per hour on a power budget of approximately 500 watts. This may be achieved through a very efficient heat transfer process and a number of sub-system design optimizations.

Knowledge of operating temperatures, TDS, and fluid flows provides information to allow production of potable water under a wide range of ambient temperatures, pressures, and dissolved solid content of the source water. One particular embodiment may utilize a control method whereby such measurements (T, P, TDS, flow rates, etc) are used in  
5 conjunction with a simple algorithm and look-up table allowing an operator or computer controller to set operating parameters for optimum performance under existing ambient conditions.

While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification as will be apparent to  
10 those skilled in the art. All such variations and modifications are intended to be within the scope of the present invention as defined in the specification.